Optimal Control Method of Permanent Magnet Type Reluctance Generator for Wind Generation

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URL	http://hdl.handle.net/10097/58582

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学 位 論 文 題 目	Optimal Control Method of Permanent Type Reluctance Generator for Wind Generation（風力発電用永久磁石型リラクタンスジェネレータの最適制御法）
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論文内容要約

The main advantage of a permanent reluctance generator (PMRG), which is a special SRG with magnets on stator yokes, is that it does not require any excitation circuit. Control of PMRG is not simple as the torque production mechanism is inherently nonlinear and it produces considerable torque ripple compared to the conventional machines. Furthermore, it has had inevitably large torque ripples due to the doubly salient structure of both stator and rotor of the PMRG. Torque ripples propagate acoustic noise, vibrations, and mechanical stress in the turbine-shaft. Exposing to such ripples may result serious failure or damage in the wind energy conversion system (WECS). PMRG needs a power converter and rotor position sensors on account of torque ripple minimization. The main goal of this thesis is a novel algorithm consisting of a maximum power point tracking (MPPT) and torque ripple control. The novel algorithm has been tested on the PMRG based WECS by Asymmetric Half bridge(AHB) converter, which is accepted to be a traditional converter for the switch reluctance machines. The torque ripple minimization has been achieved by controlling the torque distribution in the commuting phases of the generator. In order to operate at the maximum efficiency, the reference torque is generated by MPPT algorithm, which uses a Hill Climb Search (HCS). The next step of the thesis focuses on reducing the system losses and system cost via delta connection-FB Converter. The delta connection-FB Converter are more successful output power and torque ripple minimization as compared with AHB.

1. INTRODUCTION

The roles of renewable energy systems (RESs) in worldwide electric power generation have been increasing fast because of the fact that they are environmentally friendly and have no fuel costs. A WECS seems to be the most promising one among the other RESs[1].

Although having improved technology, power generation cost of the WECS is still higher than that of fossil energy conversion systems. In order to improve the WECS technology, new type generators and power electronic drive circuits are required to be developed. A permanent magnet reluctance generator (PMRG), which is a special switched reluctance generator (SRG) with magnets on stator yokes, seems to have potential to meet these requirements. The main advantage of the PMRG is that it does not require any excitation circuit during energy conversion process [2]-[4]. However, large torque ripples inevitably occurs if any torque ripple reduction technique is not employed. They propagate acoustic noise, vibrations and mechanical stress in the turbine-shaft assembly [5] and may cause serious failure or damage in the WECS. The AHB converter is maybe accepted to be the traditional converter topology for SRGs as well as PMRGs. This thesis is first to use concentrates on torque ripple minimization in PMRGs based on phase torque commutation and presents a novel MPPT and phase torque commutation control algorithm that can be applied to the AHB converters. Thus PMRG based WECS can be protected from possible damages of large torque ripples while converting wind energy at its maximum power point (MPP).

The next step of the thesis focuses on creasing the system energy, reducing torque ripples and decrease system cost via the delta connection- Full Bridge (FB) converter topology. Commercial form as a single module for AHB converter is not available in the markets. The FB converters are commercially available as Intelligent Power Module (IPM) which includes the power electronics switches, gate drivers and protection circuits from over temperature and current, thus offering lower size and cost. This thesis proposes, for the first time, the use of full bridge converter for PMRG. The PMRG has been controlled by the algorithm that provides MPPT beside torque ripple minimization. The experimental results confirm the performance of proposed system.

2. PRINCIPLES OF PMRG BASED WECS

The PMRG is illustrated in Fig. 1. It has 6/4 poles and hence 90° rotational symmetry. Two magnets are located diametrically on the stator yoke. Assuming no magnetic saturation, phase torque is expressed as

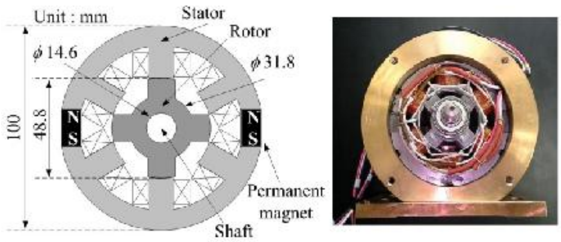
$$\tau_k = \frac{1}{2} i_k^2 \frac{dL(\theta)}{d\theta} \tag{1}$$

where i_k is phase current and $L_k(\theta)$ is phase inductance of k^{th} phase (k=A,B,C) varying with respect to the rotor position θ. Phase torque given in (1), can also be expressed in terms of phase flux ϕ_k and air gap reluctance R_{gk}:

$$\tau_k = \frac{1}{2} \phi_k^2 \frac{dR_{gk}(\theta)}{d\theta} \tag{2}$$

The mechanical power P_m captured by a wind turbine is expressed as

$$P_m = \frac{1}{2} \rho A C_p(\lambda, \beta) R^2 V_m{}^3 \tag{3}$$



Core material	:35H300	Magnet material	:NdFeB
Stator outer diameter	:100 mm	Residual flux den.	:1.27 T
Rotor outer diameter	:48.8 mm	Coercive Foce	:975 kA/m
Stack length	:50 mm	Recoil permeability	:1.037
Number of winding/pole	:106 turns	Magnet length	:18 mm
Air gap length	:2 mm	Magnet width	:12mm

Fig. 1. Technical specifications of 6/4 PMRG

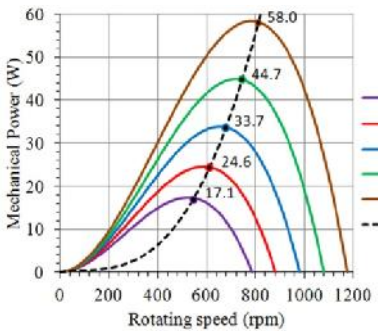


Fig. 2. Power curves of the wind turbine system

where ρ is air density, C_P is power coefficient depending on the blade pitch angle β and tip speed ratio (TSR) λ, R and V_w are respectively the blade radius and the wind speed. A wind turbine can be characterized by the curves of mechanical power vs. angular speed (P_m-ω_m) at fixed wind speeds. Such a graph is given in Fig. 2 for the wind turbine assembly that is employed in this work.

3. TORQUE RIPPLE AND MPTT CONTROLLED A DELTA CONNECTION-FB CONVERTER

The AHB converter is well known for SRGs, particularly for PMRGs. A PMRG driven WECS 6/4 PMRG accompanied with a 3-phase AHB converter is given schematically in Fig. 3. The torque ripple-MPPT algorithm can be applied to the AHB converter [6],[7]. However, the AHB converter is not commercially available in the markets. A delta connection-FB converter topology, which has the same number of switches, should be preferred to reduce size and cost. 3-phase FB converter is probably the most suitable one to which new algorithm can be directly applied.

The delta connection-FB converter topology for PMRG is presented in Fig. 4. The switching scheme of the transistors employed in the A delta connection-FB converter is illustrated in Fig. 5. Because the PMRG has 6/4 poles, the switching pattern of each phase has period of 90°. The patterns are shifted from one another by 30°. Switching in a phase is executed within the periods of negative slope of corresponding phase inductance profile.

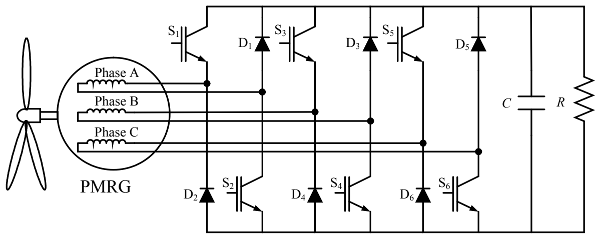


Fig.3. The 6/4 PMRG controlled by an AHB converter

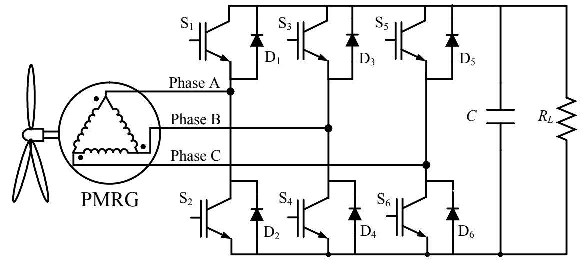


Fig.4. The 6/4 PMRG controlled by the delta connection-FB converter

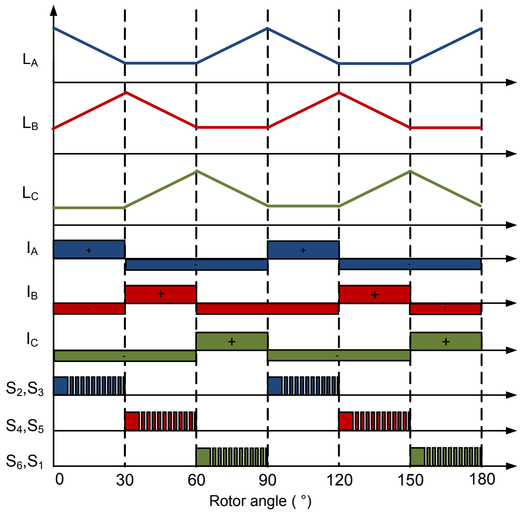


Fig.5 Switching scheme of delta connection- FB converter

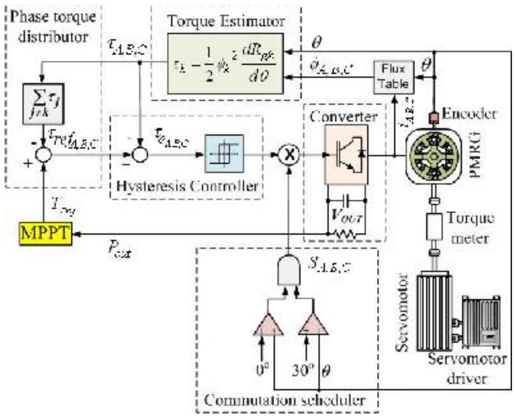


Fig.6 Torque ripple minimization system

The flowchart of the control algorithm is illustrated in Fig. 6. It is named as torque ripple minimization -assisted MPPT control because it allows torque ripple control of the PMRG while converting wind power at its maximum MPP. The MPPT algorithm generates T_{ref} for torque ripple control while receiving electric power output as input. Controlling T_{ref} by MPPT affects the generator loading, and hence the speed of generator-wind turbine system. This property allows searching MPP on the wind-turbine characteristics. The MPPT algorithm changes T_{ref} with a torque step ΔT_{ref} and then observes the change in the output power (ΔP) of the converter. If the change in power is positive, then, the same ΔT_{ref} is kept for the next searching of MPP. Otherwise, ΔT_{ref} is negated. The MPPT algorithm is independent of the system, load and wind characteristics.

Torque ripple control requires the total reference torque T_{ref} from the MPPT system. Generation of gate signals can be summarized as follows: In order to obtain reference torque of each phase, total reference torque is subtracted from the sum of estimated torques of other phases. For example, reference phase torque τ_{refA} can be found by subtracting the sum of τ_B and τ_C from T_{ref}. Then, the phase torque error signal τ_e is generated by subtracting the estimated phase torque from respective reference torque τ_{ref}. The hysteresis controller produces required gate signals to confine torque ripples in a predefined band. To use only the desired portion of the gate signal, the output of the hysteresis band is multiplied by output of a commutation scheduler.

4. EXPERIMENTAL RESULTS

The novel converter with torque ripple control-assisted MPPT algorithm has been experimentally tested on the PMRG based WECS, as seen in Fig. 6. A PC - controlled servomotor has been employed to obtain the dynamic behavior of the wind turbine. Control and monitoring of the system have been achieved by ControlDesk program via dSPACE DS1103 digital processor which can be programmed by Matlab/Simulink and dSPACE's real time interface. The capacitor and load on electric side are selected to be 4.7 mF and 50Ω, respectively. Turn-on and off angles of each transistor are respectively adjusted to 0° and 30°. The PMRG based WECS has been subjected to wind speed of 5 m/s. Fig. 7 displays the results of AHB converter case.

The control algorithm allows keeping variation of total torque within a small band, that is, between 0.2 Nm and 0.55 Nm. On the other hand, the electrical power output is about 21 W while the wind turbine power is about 33.7 W. The turbine power implies that WECS operates at its MPP (see Fig. 3). With this wind speed, the conversion efficiency is about 62%. The results of the delta connection-FB converter are demonstrated in Fig. 8. The total torque changes between 0.35 Nm and 0.59 Nm which is about 54% ripple on total torque while the system is working at its MPP. The power output is about 26.2 W and hence the efficiency is about 77.5%. As compared to previous results, the WECS with novel converter provides higher efficiency than the AHB converter. The experimental results presented here prove the effectiveness of new configuration.

5. CONCLUSION

This research introduces, for the first time, a novel control with FB converter configuration for PMRG based WECSs. The configuration employs a 3-phase FB converter and a torque ripple minimization -assisted MPPT control algorithm. The single package of FB converter has widespread use in different applications. Therefore, it can be found easily in the markets, which makes it much cheaper than AHB converter. The delta connection-FB converter topology has higher performance on PMRG because of bidirectional current flow capability. The novel control– the delta connection-FB converter topology configuration allows obtaining less torque ripple and hence less mechanical vibration and stress on mechanical side as well as higher power output and efficiency on the electrical side of the system. Although this the PMRG employed in this work has a power of few watts, it is enough to demonstrate the superiority of the delta connection-FB converter. This research may lead PMRGs to play much more significant role in WECSs.

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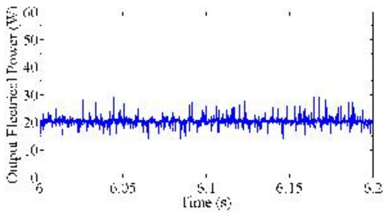

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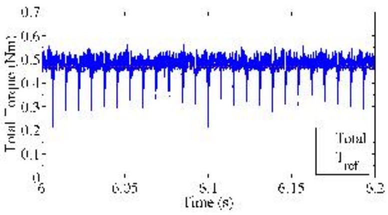

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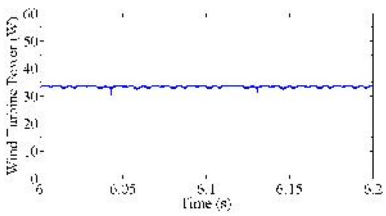

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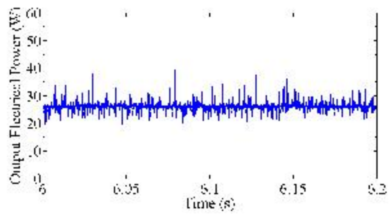
Fig. 7. Experimental result of the AHB converter



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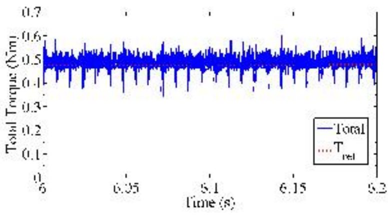

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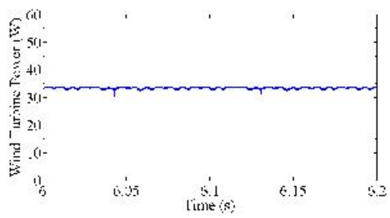

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Fig. 8. Experimental result of the delta connection-FB Converter